Plants for Life Support in Space

Raymond M. Wheeler
NASA Exploration Research and Technology Directorate
Kennedy Space Center, Florida, USA

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Human Life Support Requirements:

Inputs

	Daily Rqmt.	(% total mass)
Oxygen	0.83 kg	2.7%
Food	0.62 kg	2.0%
Water (drink and food prep.)	3.56 kg	11.4%
Water (hygiene, flush laundry, dishes)	26.0 kg	83.9%
TOTAL	**31.0 kg**	

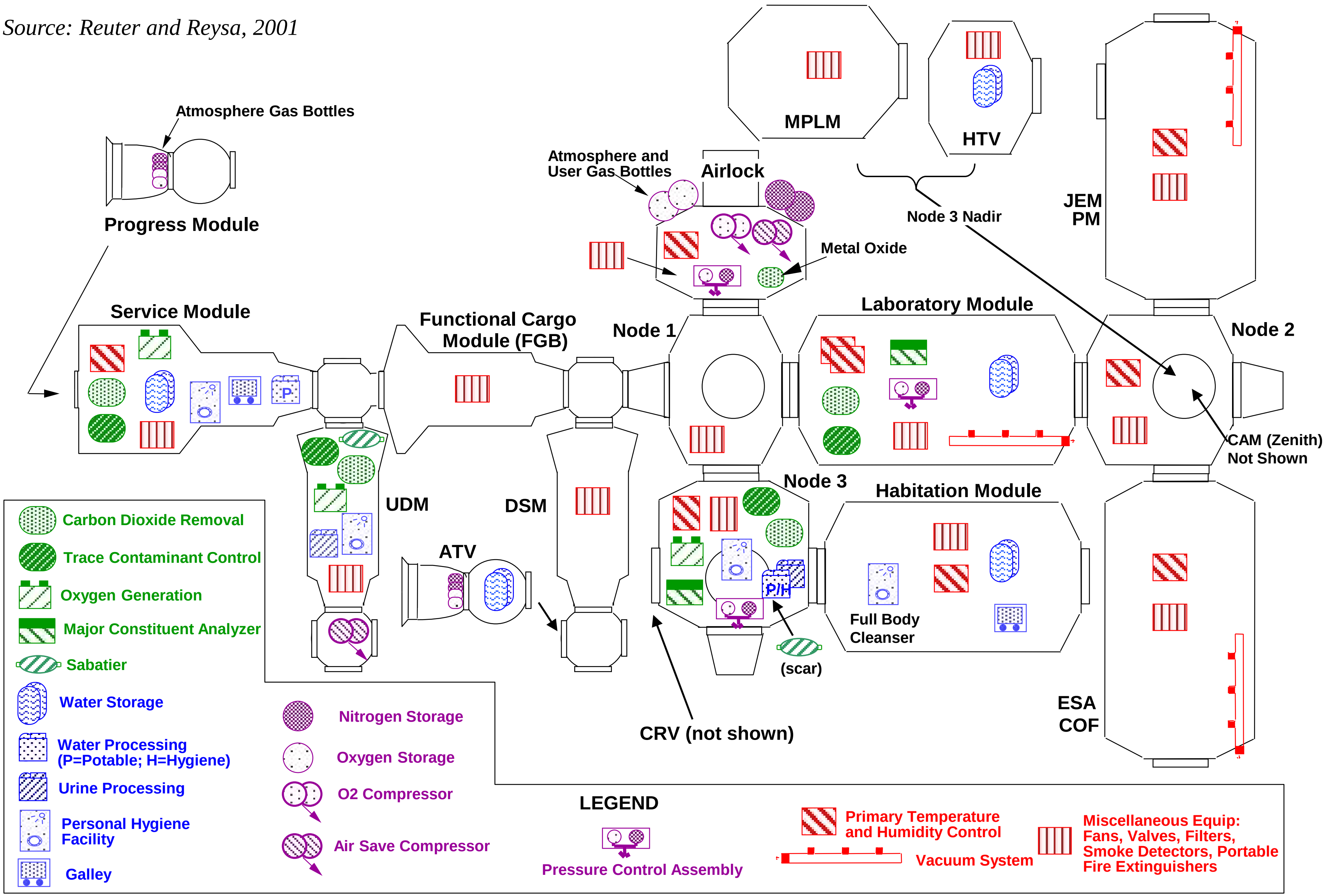
Outputs

	Daily	(% total mass)
Carbon dioxide	1.00 kg	3.2%
Metabolic solids	0.11 kg	0.35%
Water	29.95 kg	96.5%
(metabolic / urine		12.3%)
(hygiene / flush		24.7%)
(laundry / dish		55.7%)
(latent		3.6%)
TOTAL	**31.0 kg**	

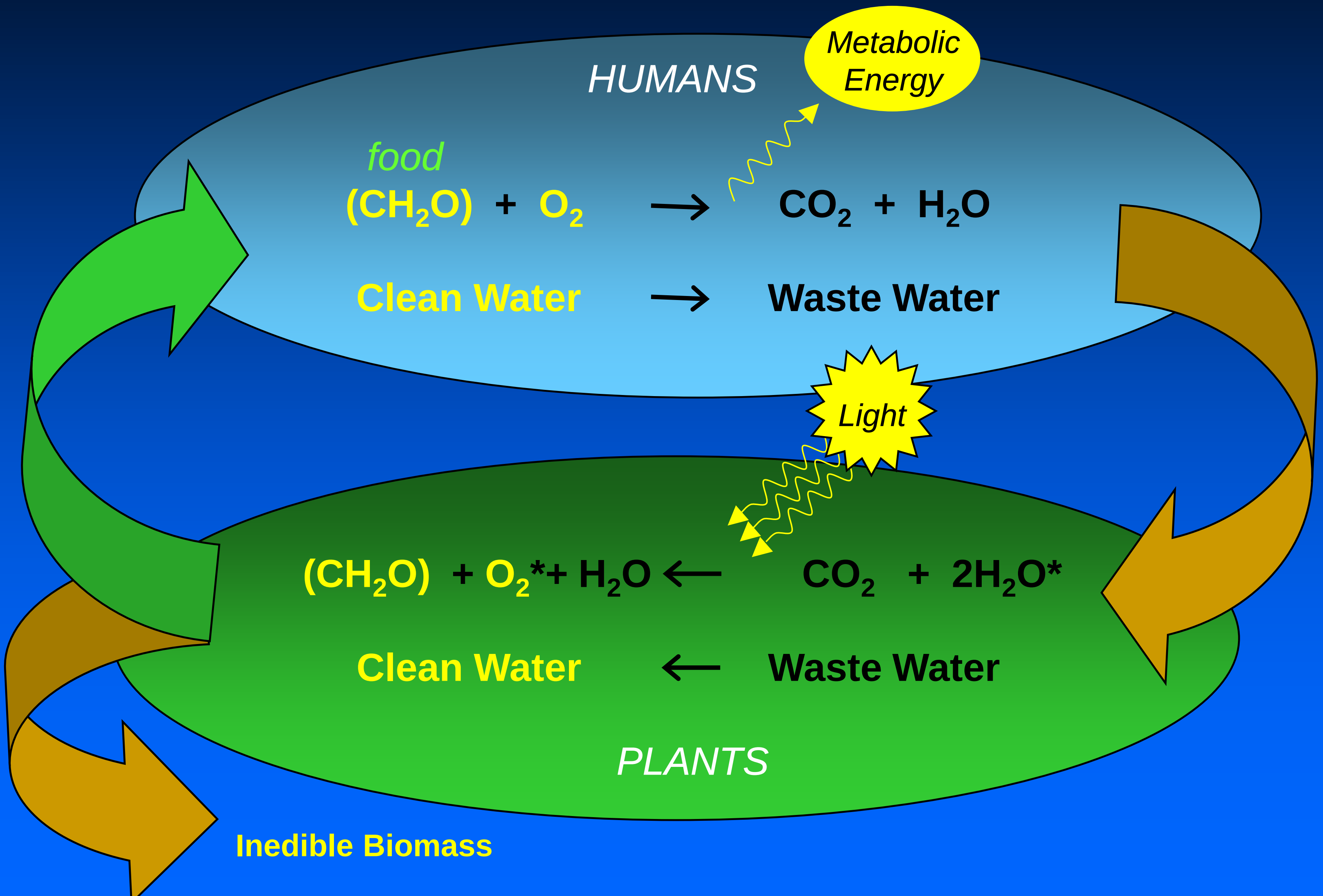
Source: NASA SPP 30262 Space Station ECLSS Architectural Control Document
Food assumed to be dry except for chemically-bound water.

International Space Station Life Support Systems

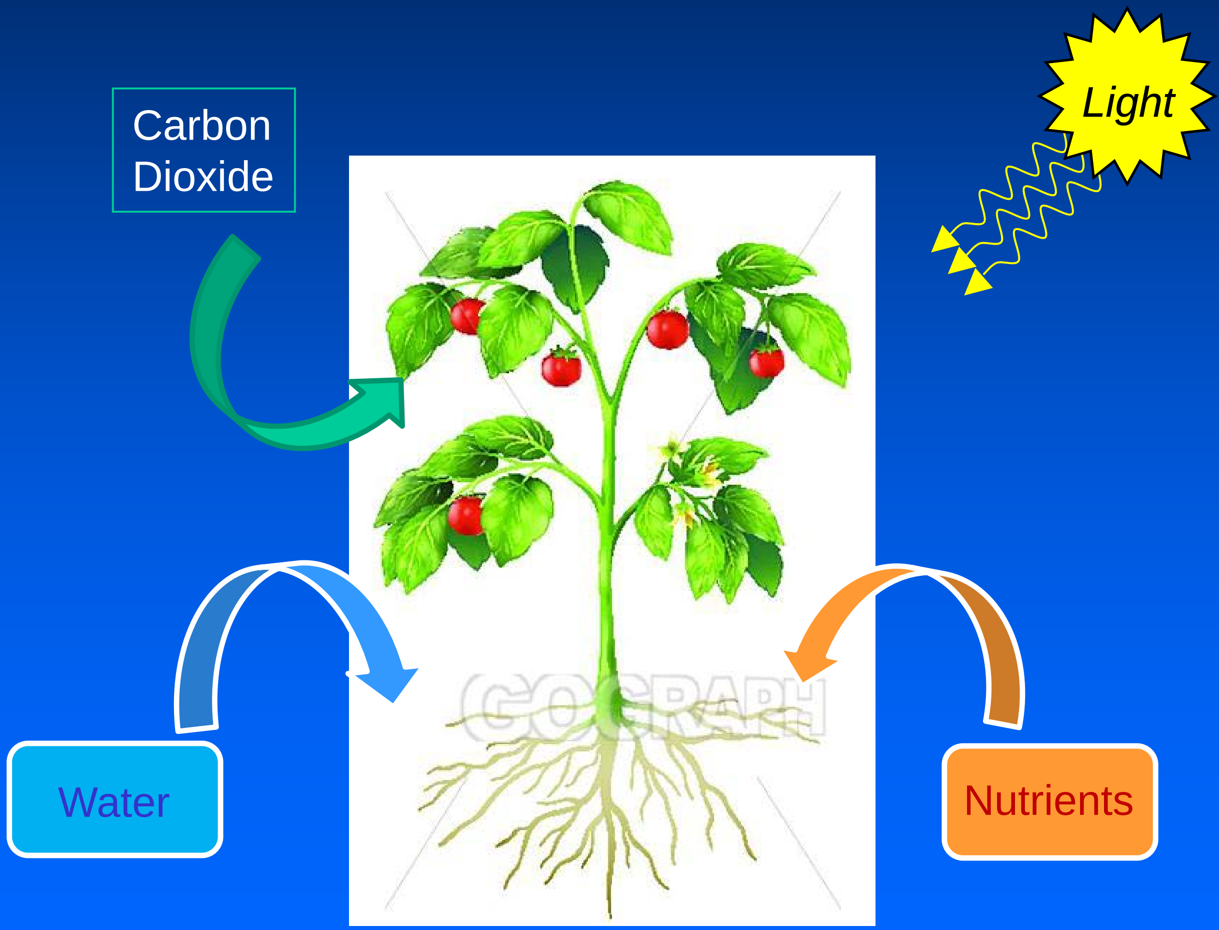
Source: Reuter and Reysa, 2001



Plants for “Bioregenerative” Life Support



What will it take to grow plants in space ?



Crop Considerations for Space

- High yielding and nutritious (CHO, protein, fat)
  - Micronutrients--antioxidants, Vitamins, minerals
- High harvest index (edible / total biomass)
- Dwarf or low growing types
- Environmental considerations
  - lighting, temperature, mineral nutrition, CO_2
- Horticultural considerations
  - planting, watering, harvesting, pollination, propagation
- Processing requirements

Some Crops for Life Support in Space

Hoff, Howe, and Mitchell (NASA)[a]	Salisbury and Clark (NASA)[b]	Crops Used in BIOS-3 (Russia)[c]	Tako et al CEEF (Japan)[d]	Waters et al. (ESA / Canada)[e]
Wheat	Wheat	Wheat	Rice	Lettuce
Potato	Rice	Potato	Soybean	Wheat
Soybean	Sweetpotato	Carrot	Peanut	Potato
Rice	Broccoli	Radish	Sweetpotato	Sweetpotato
Peanut	Kale	Beet	Sugar Beet	Rice
Dry Bean	Lettuce	Nut Sedge	Carrot	Bean
Tomato	Carrot	Onion	Tomato	Beet
Carrot	Canola	Cabbage	Spinach	Cabbage
Chard	Soybean	Tomato	Shungiku	Broccoli
Cabbage	Peanut	Pea	Chinese Cabbage	Cauliflower
	Chickpea	Dill	Pea	Carrot
	Lentil	Cucumber	Onion/Leek	Kale
	Tomato	Salad spp.	Komatsuna	Onion
	Onion		Pepper	
	Chili Pepper			

[a] Hoff, Howe, and Mitchell (1982); [b] Salisbury and Clark (1996); [c] Gitelson and Okladnikov (1994).
[d] Tako et al. (2010); [e] Waters et al. (2002)

Growing Plants in a Controlled Environment

Recirculating Hydroponics

Why Hydroponics?

Conserves Water & Nutrients
Eliminates Water Stress
Optimizes Mineral Nutrition
Facilitates Harvesting

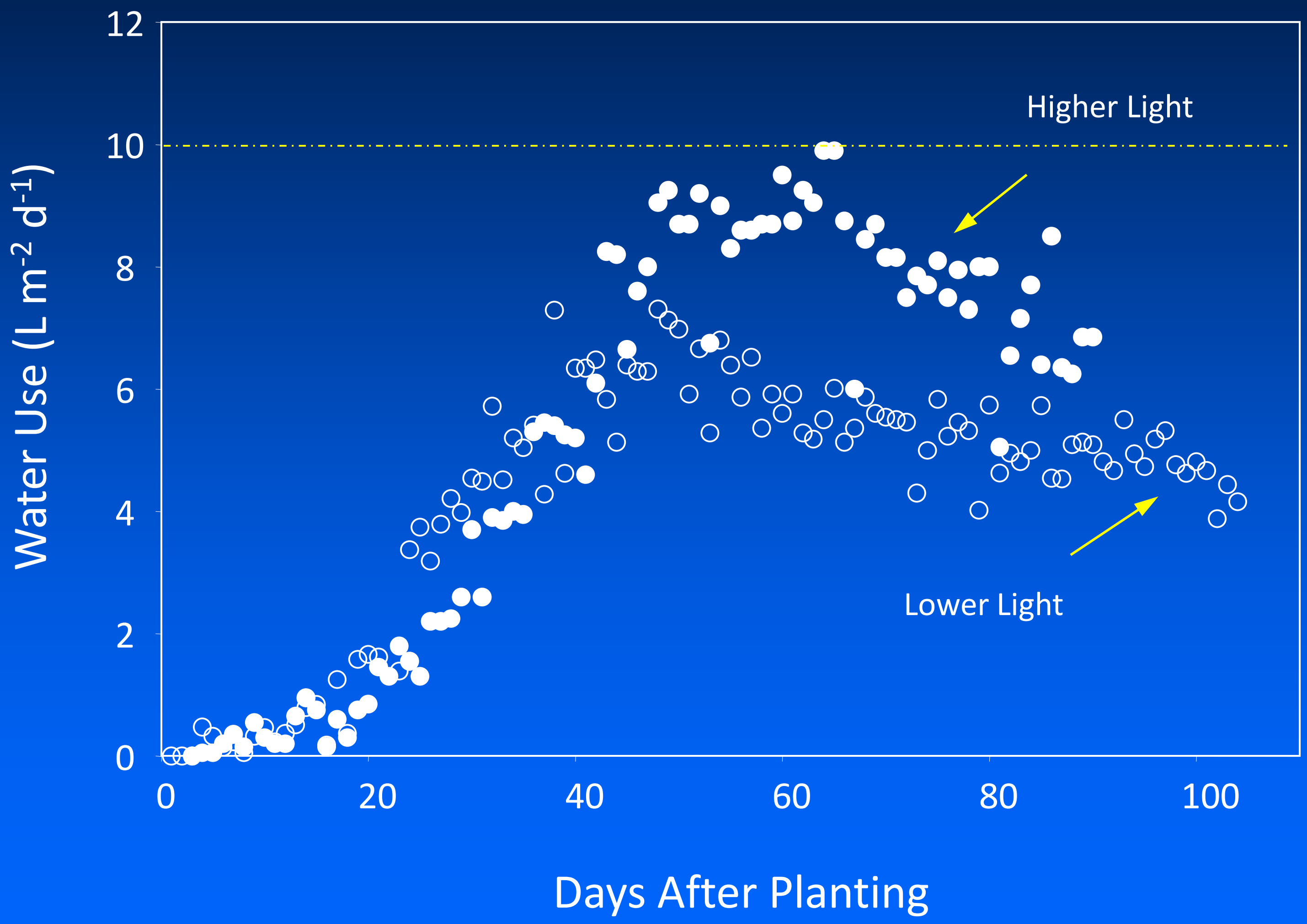
Wheeler et al., 1999. Acta Hort.

Root Zone Crops in Nutrient Film Technique (NFT)

Wheeler et al., 1990. Amer. Potato J. 67:177-187; Mackowiak et al. 1998. HortScience 33:650-651

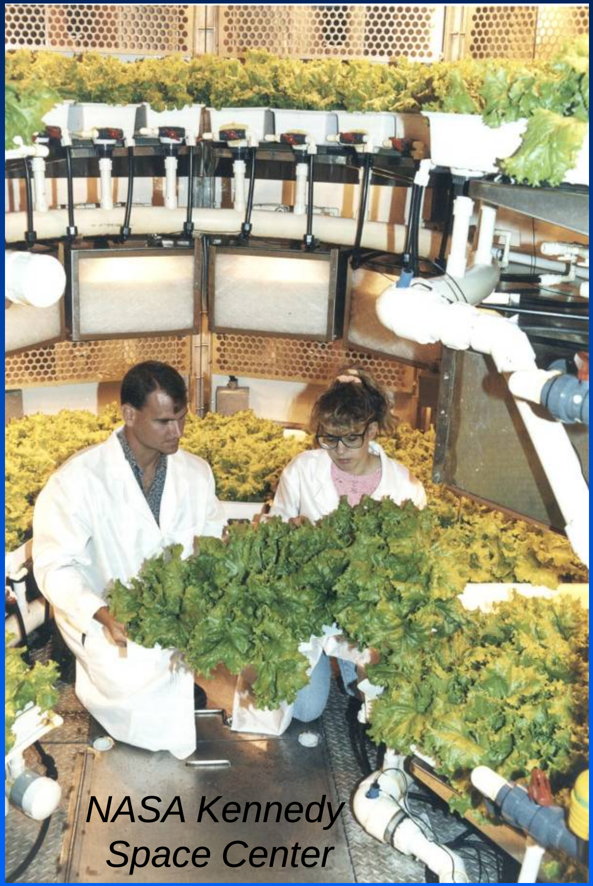
Fig. 7

Plants use a lot of Water !

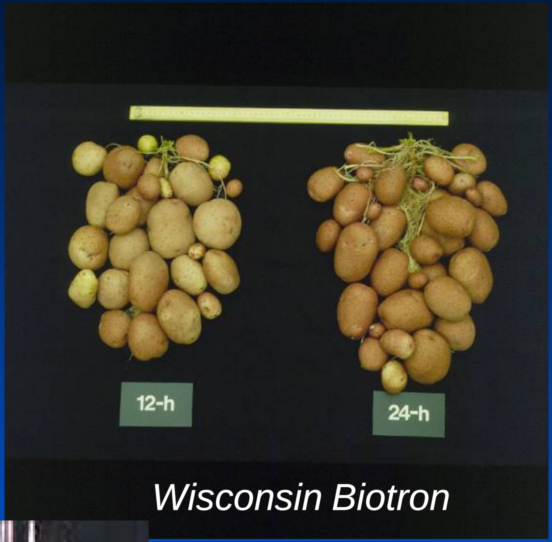


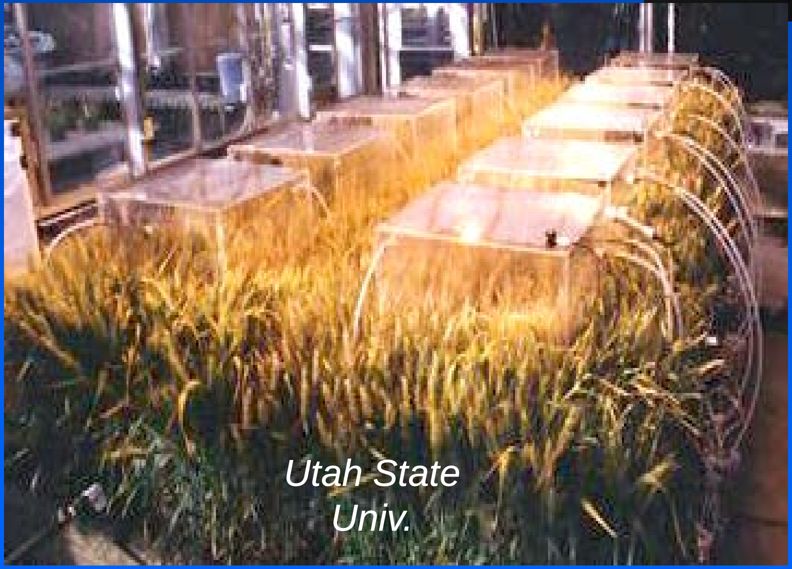
Wheeler. 2006. Potato Research 49:67-90.

High Yields from NASA Sponsored Studies



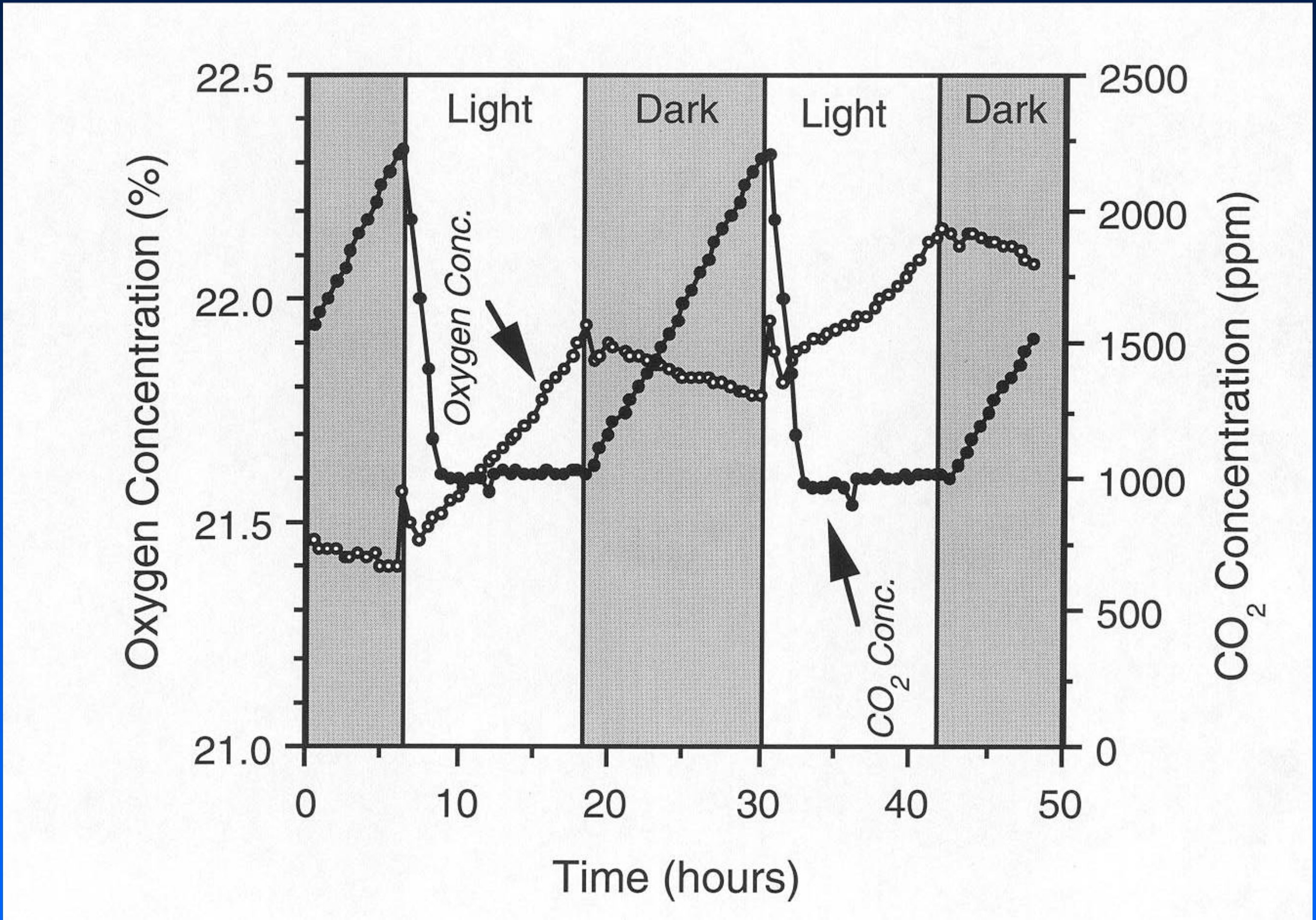
Wheat - 3-4 x World Record
Potato - 2 x World Record
Lettuce-Exceeded Commercial Yield Models





Bubgee, B.G. and F.B. Salisbury. 1988. Plant Physiol. 88:869-878.
Wheeler, R.M., T.W. Tibbitts, A.H. Fitzpatrick. 1991. Crop Science 31:1209-1213.

Photosynthetic CO_2 Uptake / O_2 Production
(20 m^2 Soybean Stand)



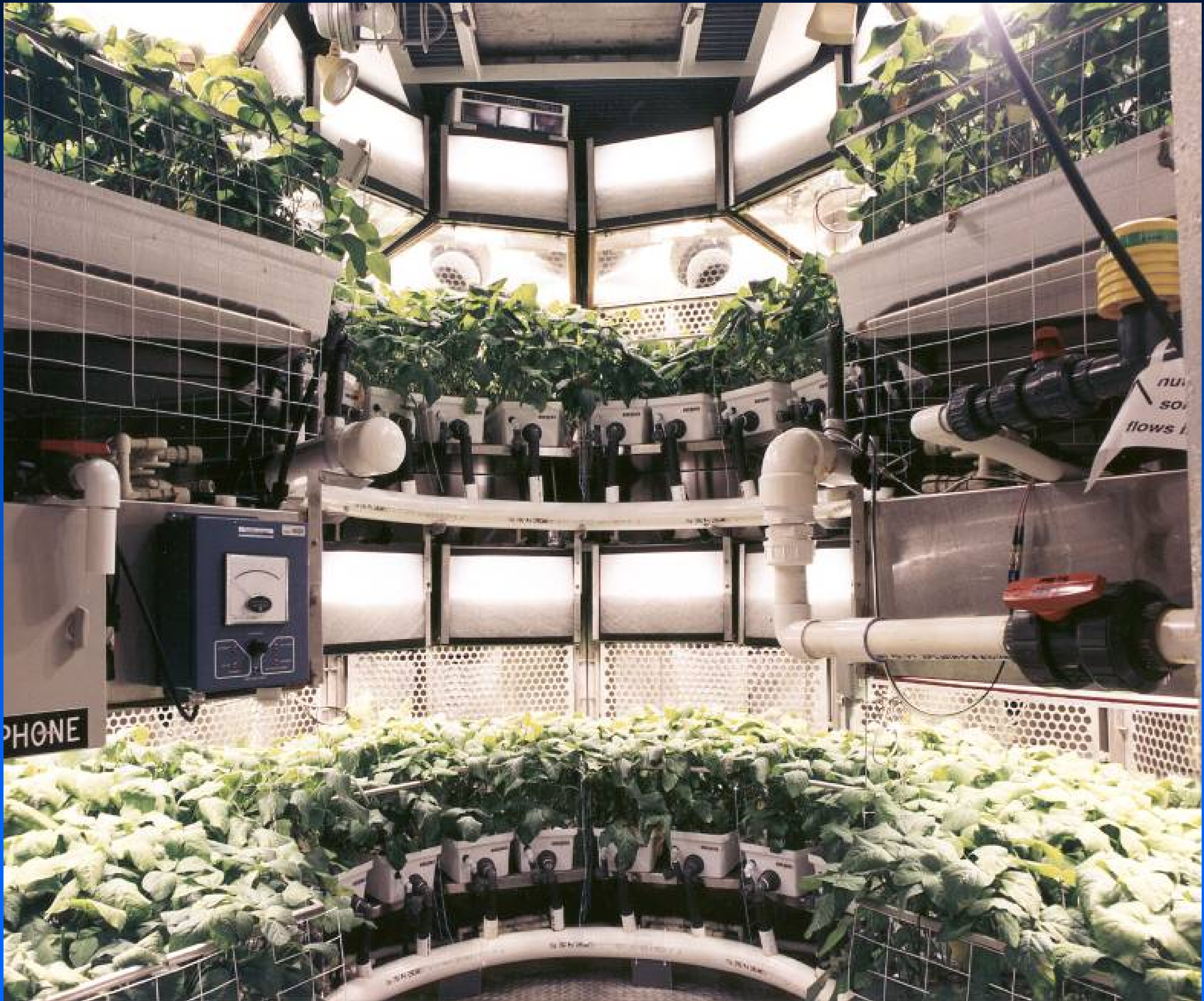
Wheeler. 1996. In: H. Suge (ed.) Plants in Space Biology.

NASA's Biomass Production Chamber (BPC)

20 m^2 growing area; 113 m^3 vol.; 96 400-W HPS Lamps;
400 m^3 min^{-1} air circulation; two 52-kW chillers

NASA's Biomass Production Chamber (BPC)

…an early example of a Vertical Agriculture Systems

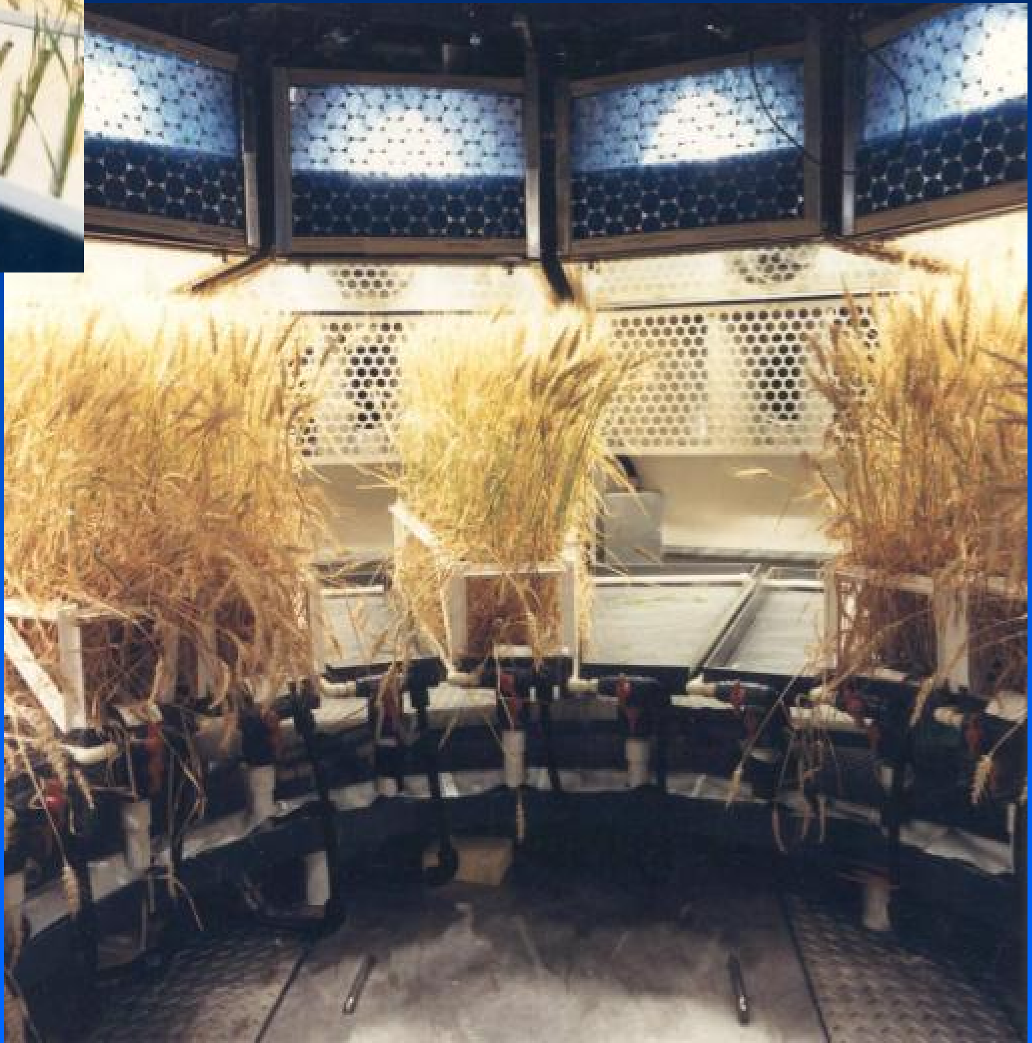


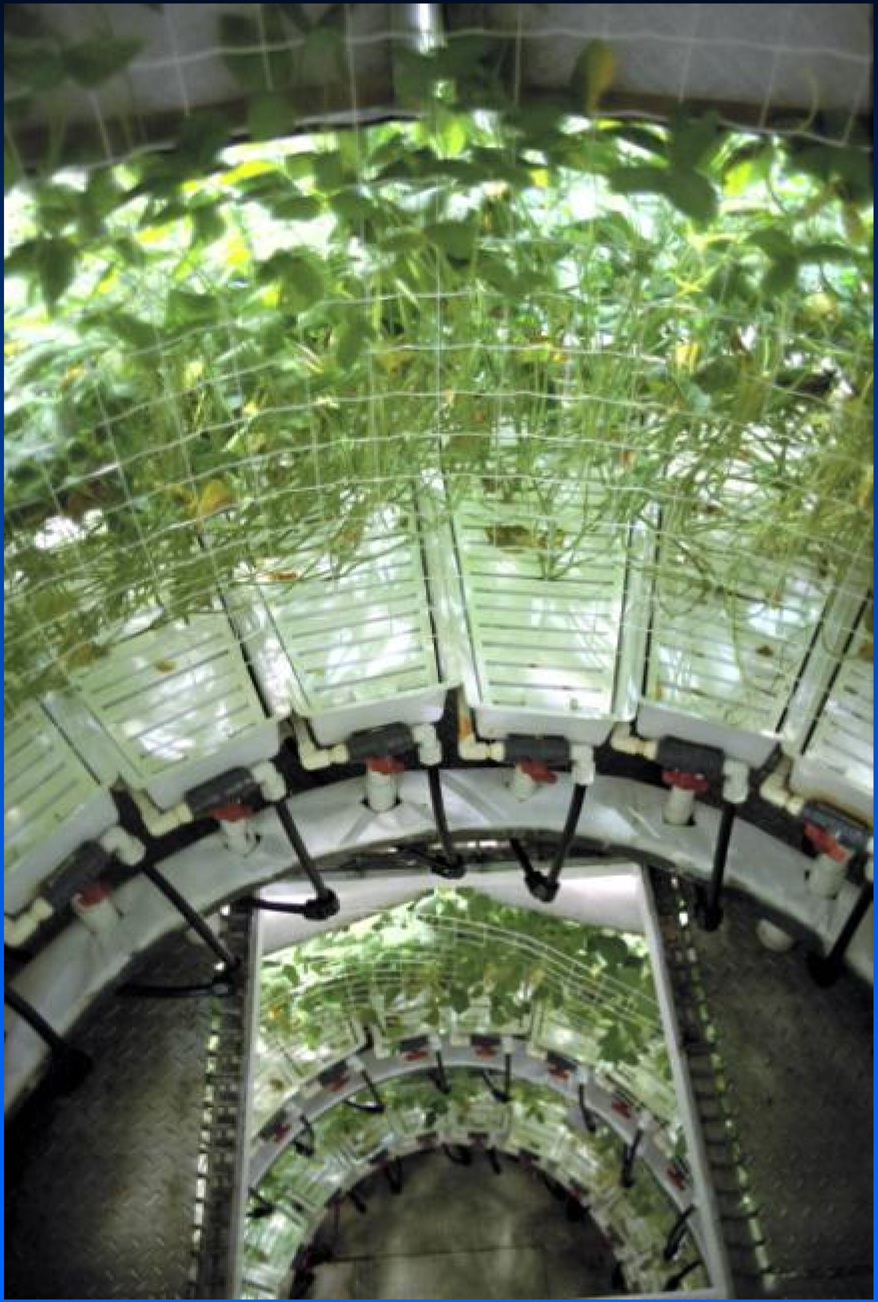
Wheat

(Triticum aestivum)

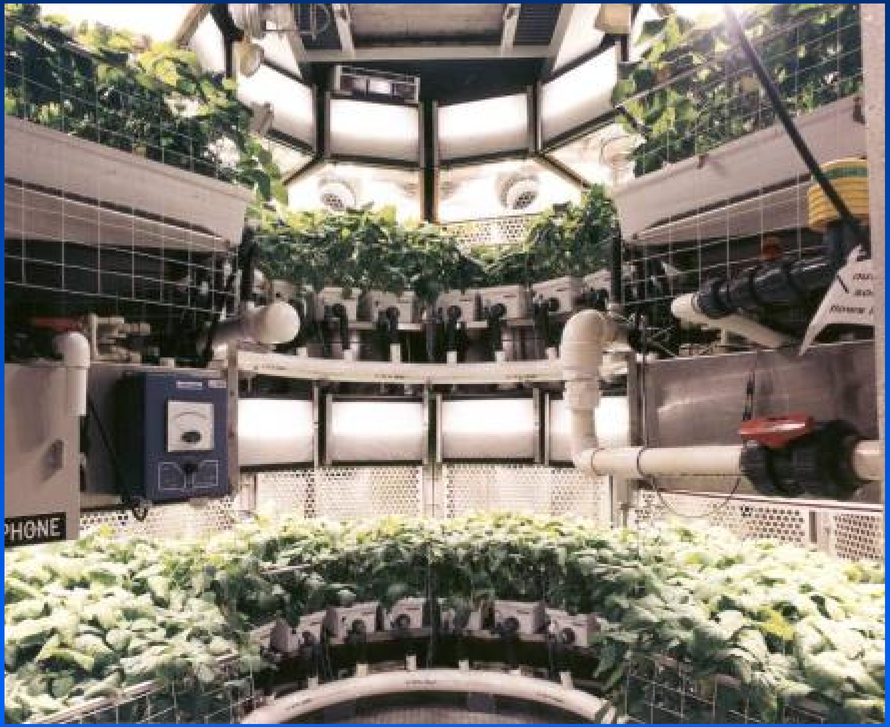
planting

harvest

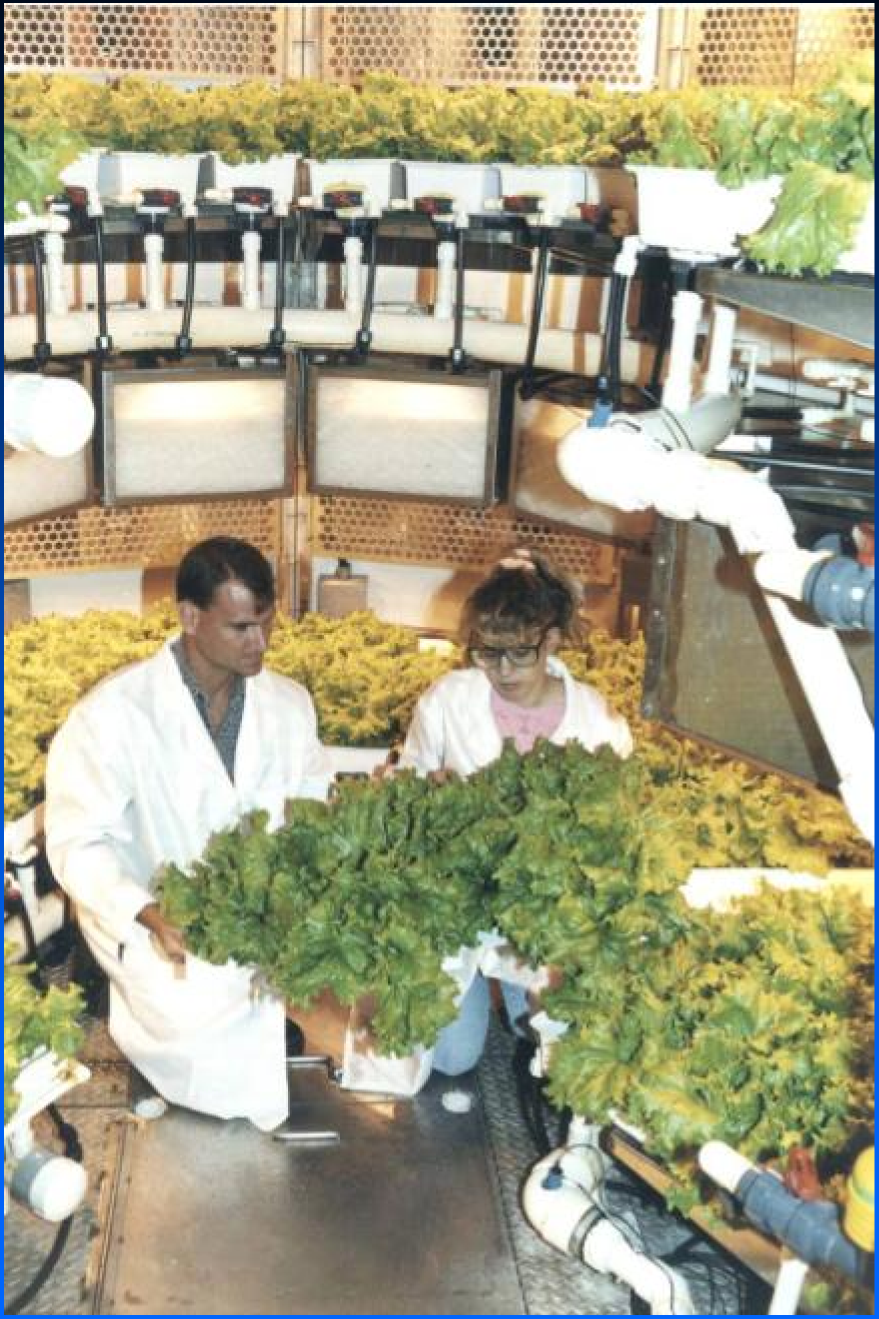




Soybean
(Glycine max)



Lettuce
(Lactuca sativa)

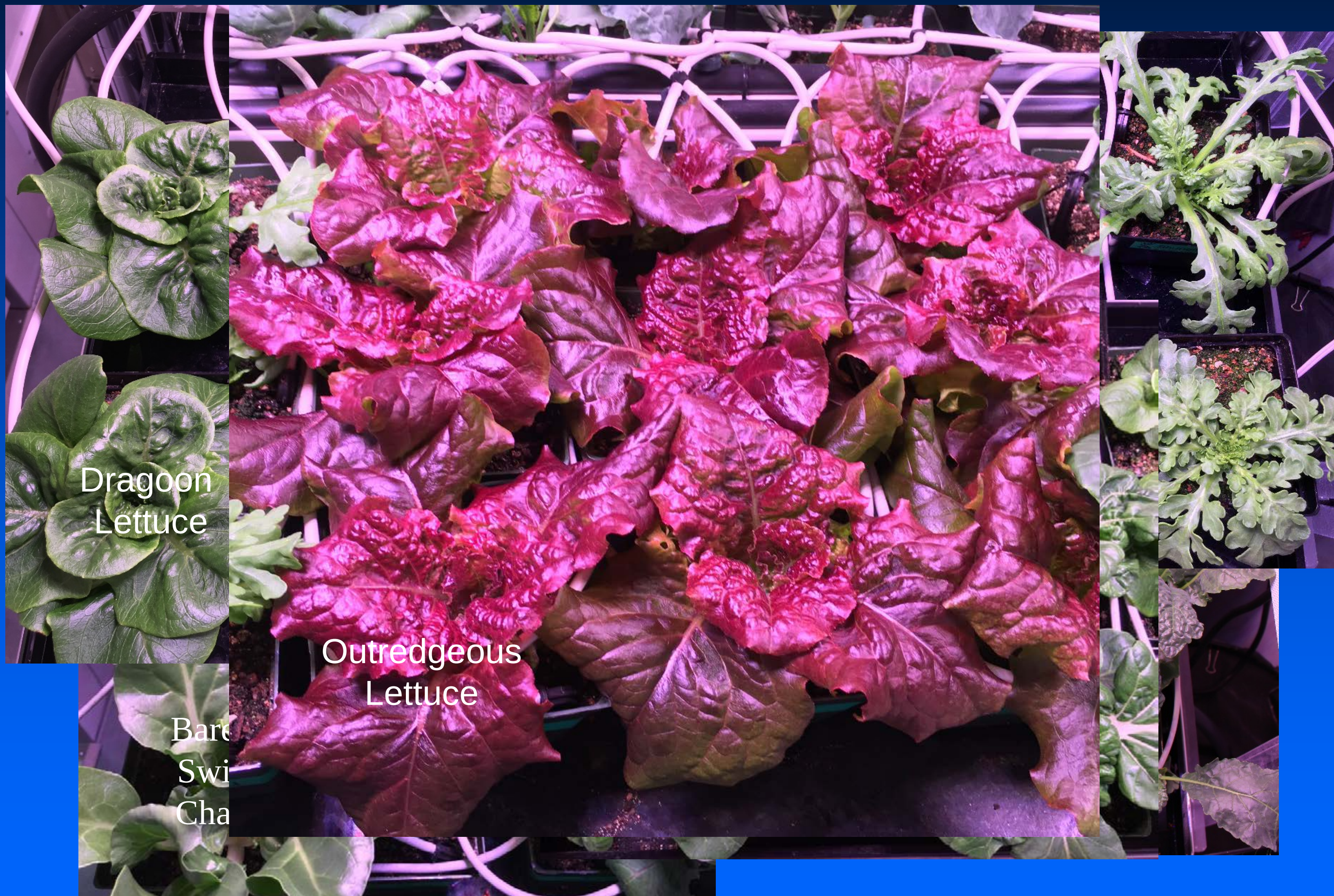


Potato

(Solanum tuberosum)

Some Other Crops Tested for Possible Space Life Support

New Crop Testing by NASA, with Help from "Growing Beyond Earth Challenge"



The Importance of Lighting

Lamp Type	Conversion* Efficiency	Lamp Life* (hrs)	Spectrum
• Incandescent/Tungsten**	5-10%	2000	Intermd.
• Xenon	5-10%	2000	Broad
• Fluorescent***	20%	5,000-20,000	Broad
• Metal Halide	25%	20,000	Broad
• High Pressure Sodium	30-35%	25,000	Intermd.
• Low Pressure Sodium	35%	25,000	Narrow
• Microwave / RF Sulfur	35-40%+	?	Broad
• LEDs (red and blue)****	>40%	50,000 ?	Narrow

* *Approximate values.*

** *Tungsten halogen lamps have broader spectrum.*

*** *For VHO lamps; lower power lamps with electronic ballasts last up to ~20,000 hrs.*

**** *State-of-Art Blue and Red LEDs most efficient.*

LED Studies

Red...photosynthesis
Blue...photomorphogenesis
Green...human vision

Goins et al., 1997. J. Ex. Bot.; Kim et al. 2004 Ann. Bot.

US Patent for Using LEDs to Grow Plants Developed with NASA Funding at University of Wisconsin – WCSAR

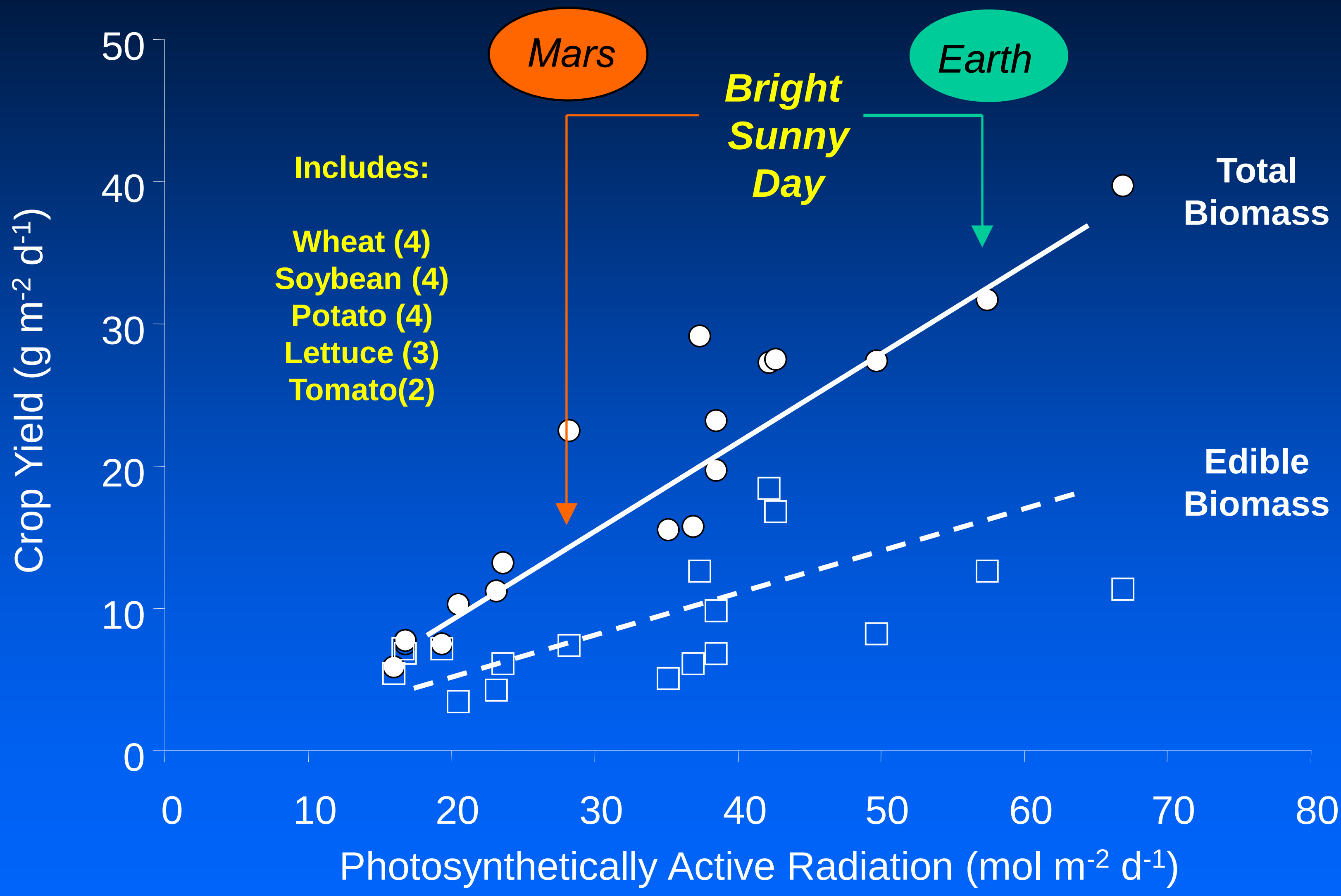
Solar Collector / Fiber Optics For Plant Lighting

2 m^2 of collectors on solar tracking drive (NASA KSC)

Up to 400 W light delivered to chamber (40-50% of incident light)
Takashi Nakamura, Physical Sciences Inc.

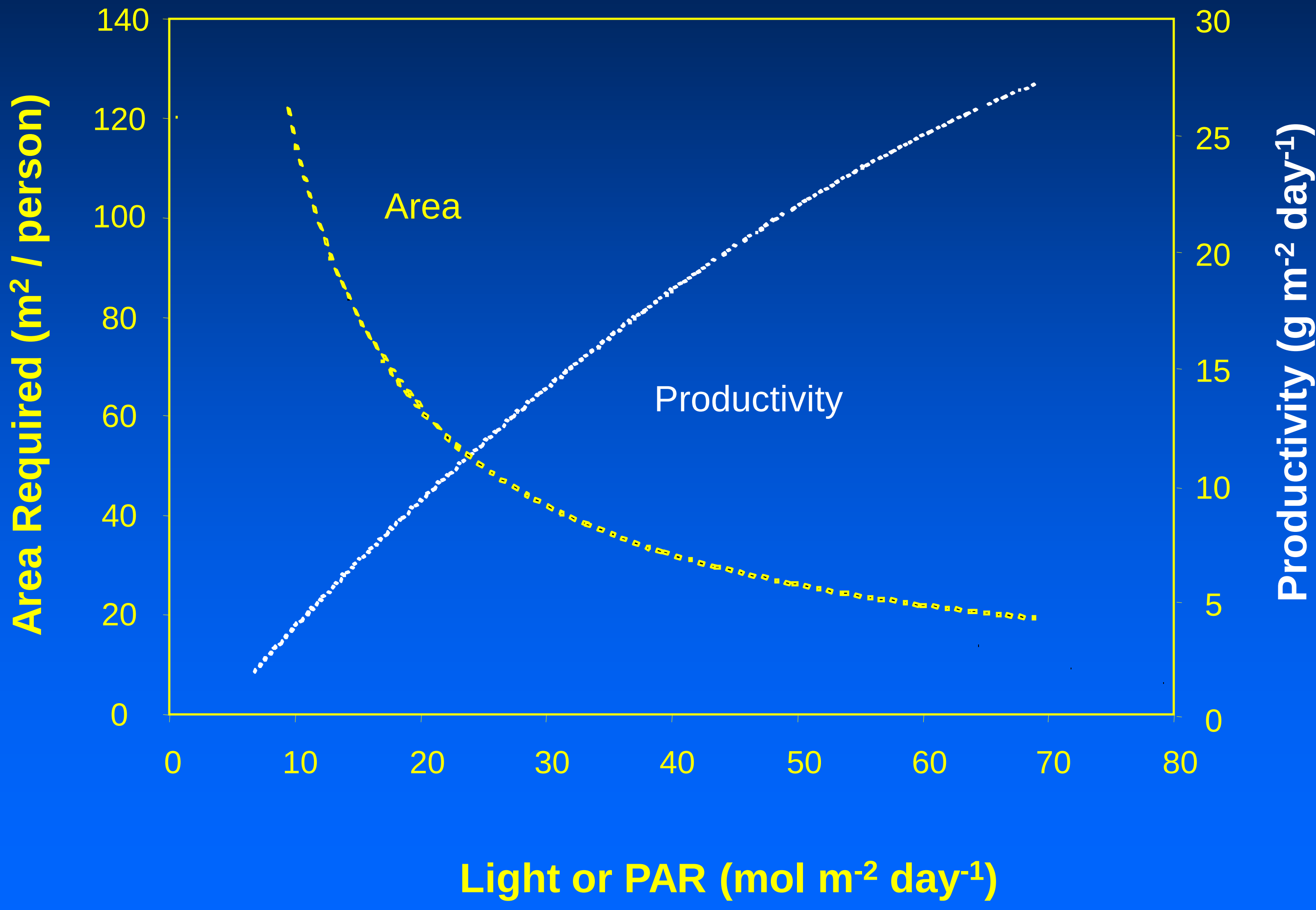
Nakamura et al. 2010. Habitation

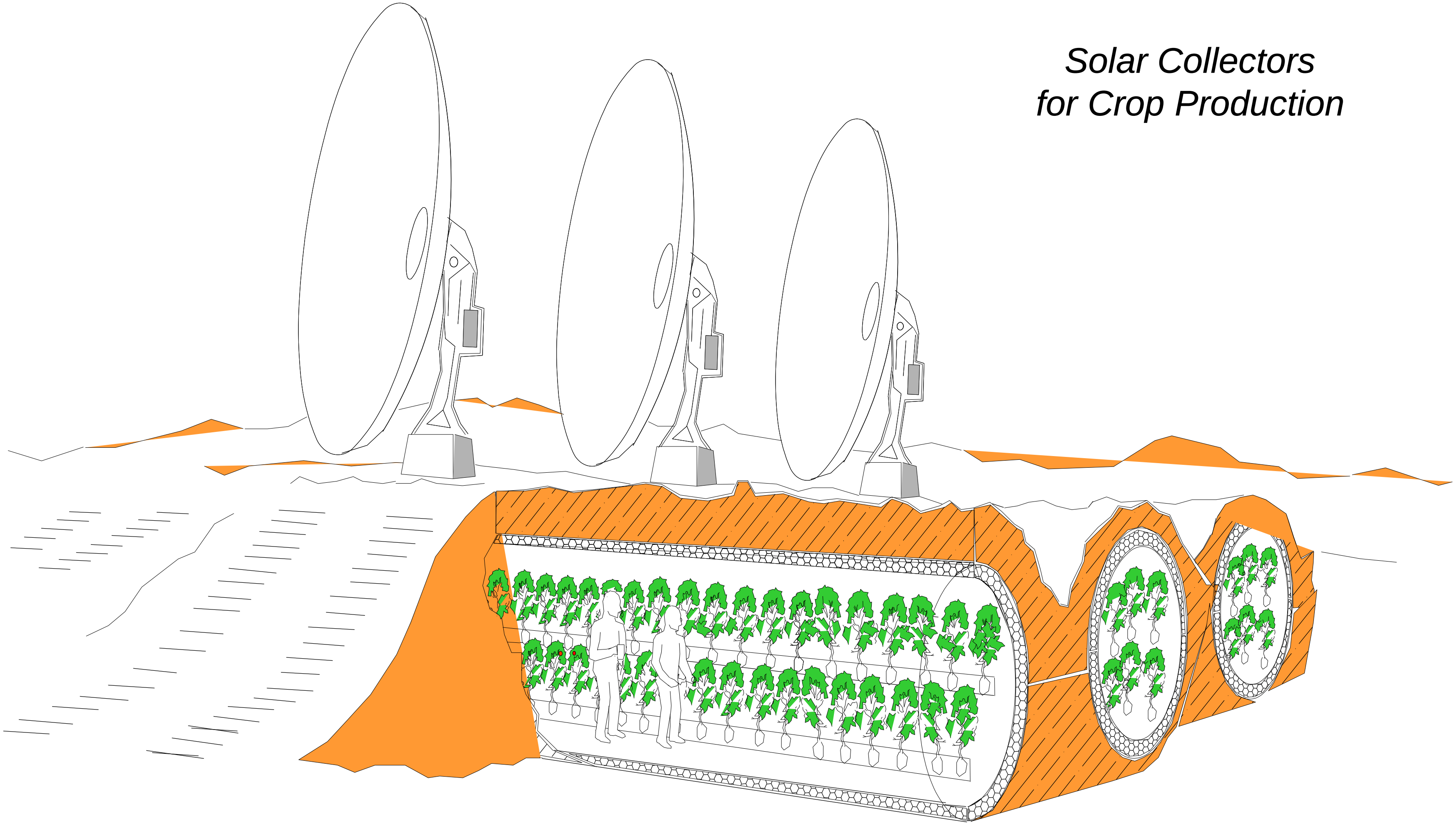
The Importance of Light for Crop Yield



Wheeler et al. 1996. Adv. Space Res.

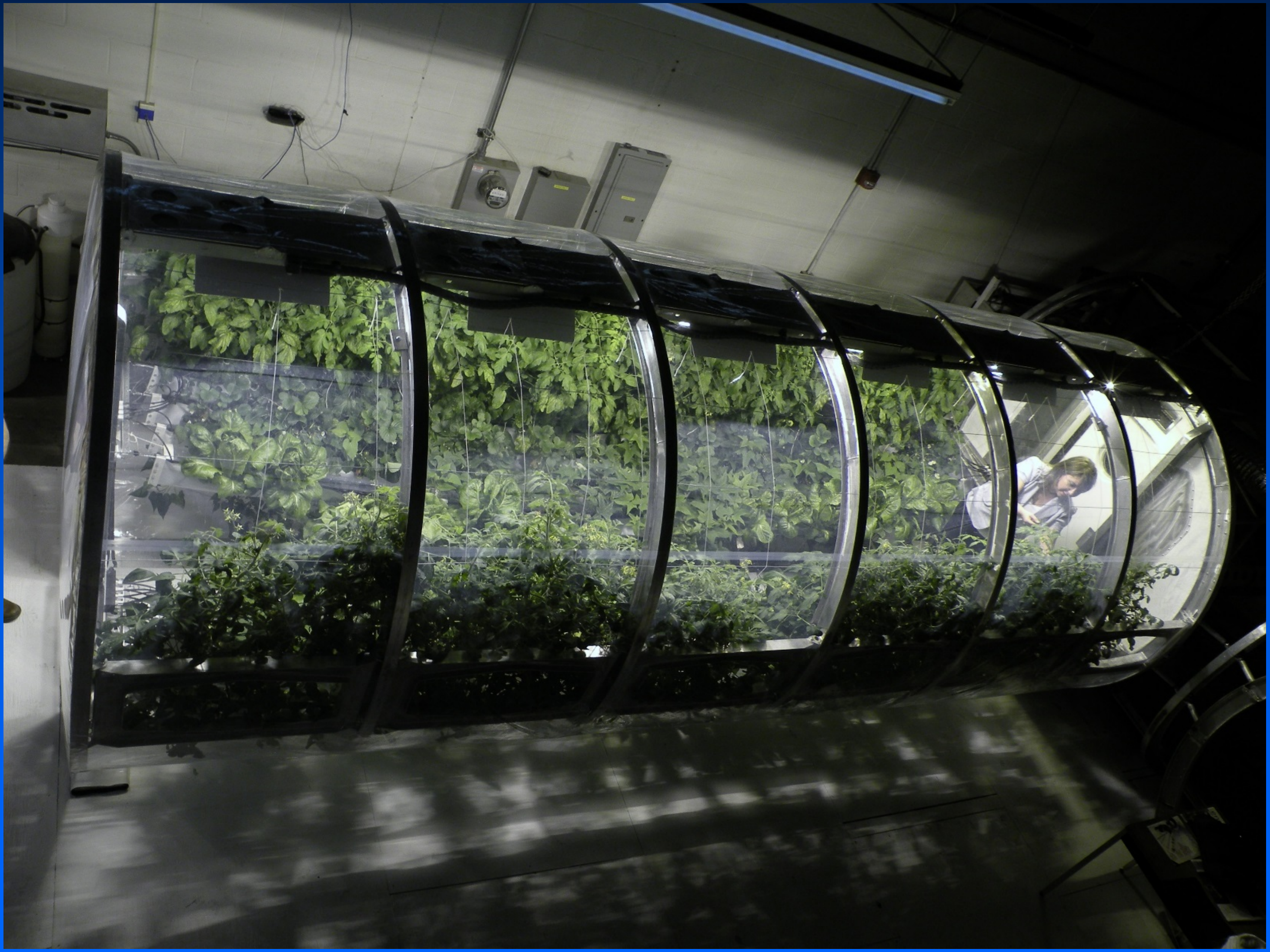
Effect of Light (PAR) on Productivity and Crop Area Requirements



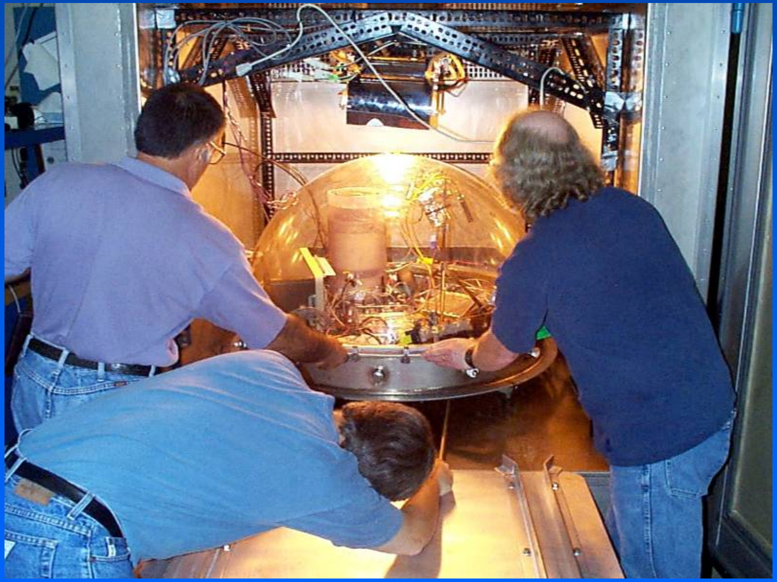


Sadler and Giacomelli, 2002
Life Sup. Biosphere Sci.

University of Arizona Lunar / Mars Greenhouse



Deployable Mars Greenhouse - Low Pressure Systems



Lettuce, radish, and wheat plants exposed to rapid pressure drop (27 days old)

Targeted Crop Selection and Breeding for Space at Utah State University

Selection of Existing Rice Genotypes

Targeted Wheat Breeding

‘Apogee’ Wheat ‘Perigee’ Wheat

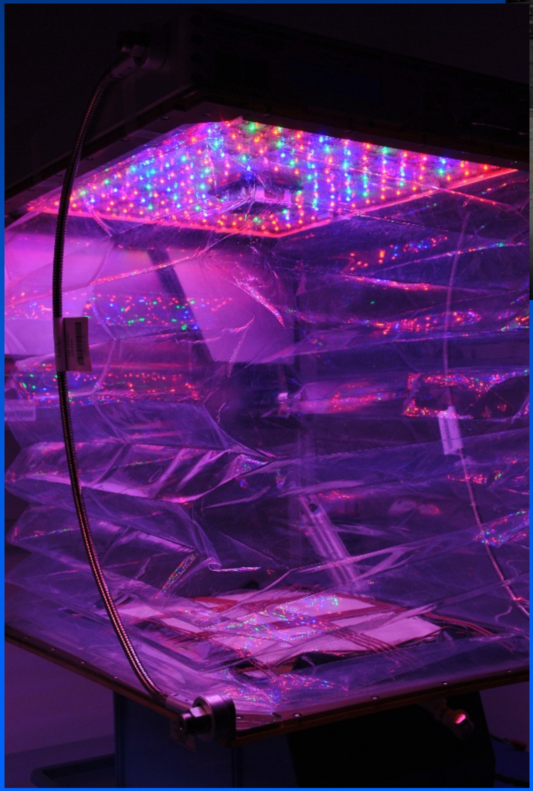
Genetic Engineering Crops for Space

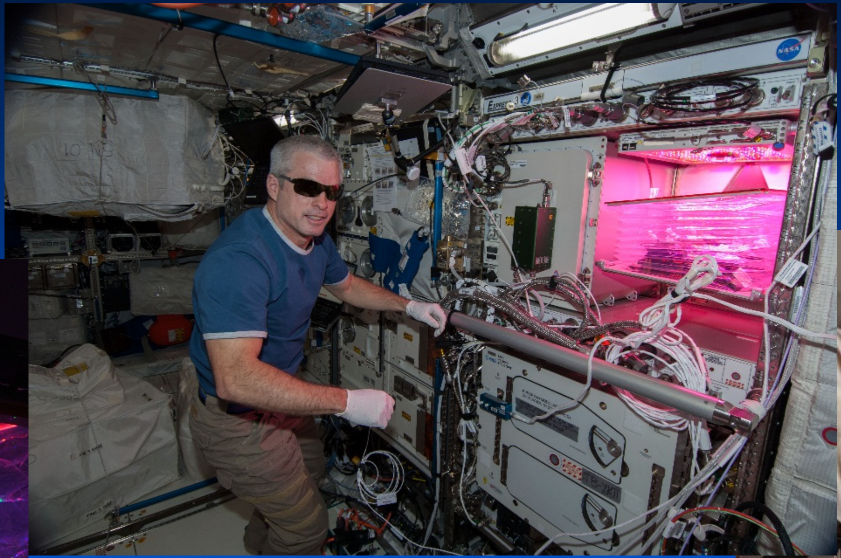
Early Flowering and Fruit Set

No Dormancy Requirements

Overexpression of FT flowering gene in plums (ARS researchers) resulted in dwarf growth habit and early flowering

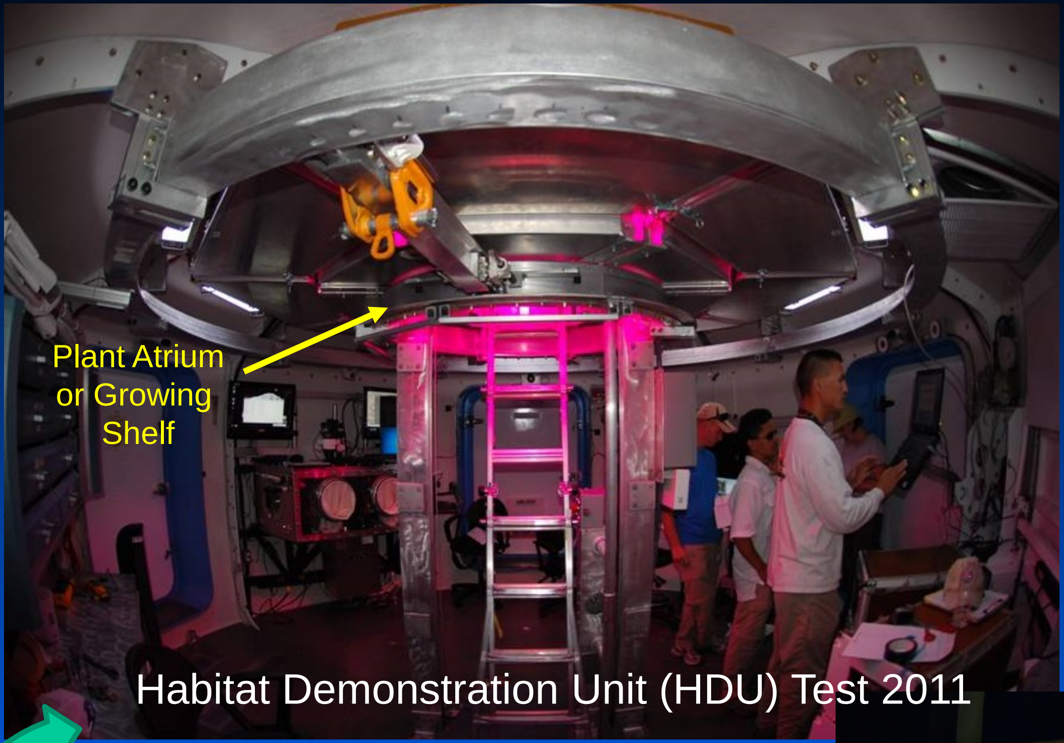
Current Plant Testing on the International Space Station—VEGGIE Plant Chamber





Passive Capillary Watering

Human Habitats and Crops for Supplemental Food

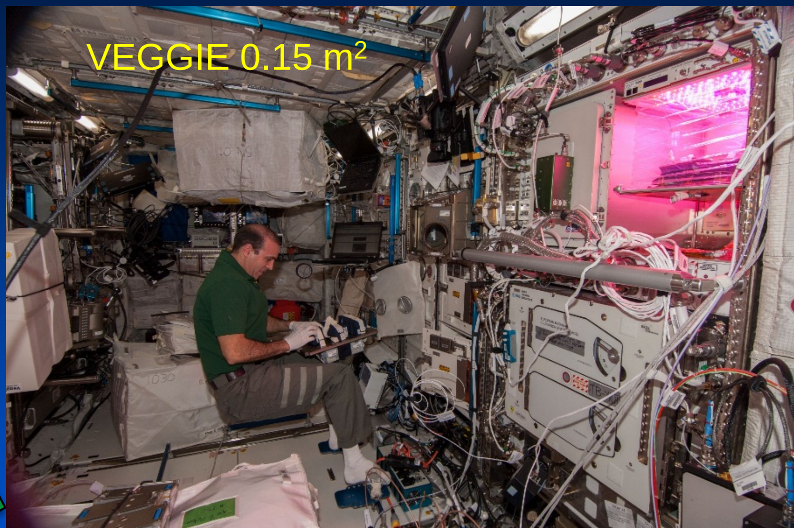


Habitat Demonstration Unit (HDU) Test 2011

NASA's HDU at Desert Test Site


HDU Test 2012

Sequential Development for Space Agriculture



Some other Benefits of Plants in Space

- Fresh Foods
  - *Colors*
  - *Texture*
  - *Flavor*
  - *Nutrients*
- Bright Light
- Aromas
- Gardening Activity

Kliss et al. 2000. Adv. Space Res.

Plant Chamber at US South Pole Station

Plants and Human Well-Being—Biophilia Concept? (E.O. Wilson)

Plants and Humans Living Together in Space
As we explore sustainable living for space, we will learn more about sustainable living on Earth

Keep Exploring !